## Synchronous Phase-Averaging Method for Machinery Diagnostics

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Turbomachinery health monitoring and fault diagnosis have always been significant technical challenges in the space and transportation industries. A reliable health-monitoring system can prevent catastrophic failures and costly engine downtime due to false alarms. To enhance engine safety and reliability, efficient and reliable diagnostic signal analysis techniques must be developed that can reduce catastrophic system failure risks and expedite the evaluation of both flight and ground test data, thereby reducing launch turnaround time.

A new algorithm, synchronous phase averaging, is being developed to provide superior signal enhancement performance for diagnostic evaluation over that of the conventional synchronous time-averaging method. A quasiperiodic synchronous (Sync) component is transformed into a pure-tone discrete component using the phase-synchronized enhancement method. Time domain averaging can then be directly applied to the resultant signal to achieve signal enhancement. The technique also eliminates the required tachometer monitoring instrumentation and allows direct application to remote sensing, such as gearbox diagnostics using a single acoustic or accelerometer measurement.

Successful application examples have been utilized to demonstrate the performance of the proposed synchronous phase-averaging techniques for gearbox diagnostics. The test data were captured from externally mounted accelerometers of a gearbox, with both input pinion and output gears having 27 teeth. The shaft rotational frequency (known as synchronous and denoted as N) is run at approximately 71.7 hertz during the tests; therefore, the predicted gear-mesh frequency is approximately 1,935 hertz (the 27th harmonic of Sync). Figure 79 shows the raw time history of an accelerometer measurement for six sets of gearbox data used to demonstrate the phase averaging during one revolution of shaft rotation. The waveforms of these raw signals have all been corrupted by background noise. To perform synchronous phase averaging, these raw accelerometer data were first synchronized to the gear-mesh frequency using the phase-synchronized enhancement method. Time domain averaging was then directly applied to the data using a fundamental frequency of 71.7 hertz (Sync). Figure 80 shows the resulting enhanced signals, each over a full cycle of shaft rotation for the six tests. The number of ensemble averages performed in the analysis is 500. Within this full cycle of shaft revolution, an enhanced signal with 27 cycles of oscillation is observed, which corresponds to the tooth-mesh waveform. In examining the smoothness of this waveform, a noticeable discontinuity or irregularity is readily observed in tests 6 and 7 at the 26th oscillation cycle. The discontinuity repeatedly shows up in the phase-averaged enhanced signal at other time periods within the test, indicating a gear-tooth fault within the hardware used in tests 6 and 7.

The synchronous phase-averaging analysis does not require tachometer or key-phaser input, such as the synchronous time-averaging method would require. The synchronization can be directly performed within a vibration measurement signal at any gear-mesh frequency of a chosen rotor. Since the amplitude of the gear-mesh component measured by a vibration sensor is typically strong, synchronization to various rotational frequencies within a single measurement can be achieved by tuning the phase-synchronized enhancement method reference frequency to the desired gear-mesh frequency. Therefore, the complexity of the instrumentation and data acquisition requirements is reduced.

The synchronous phase-averaging technique has considerable commercial application potential outside NASA's propulsion area. As demonstrated with the gearbox test data, this method could greatly enhance the performance for diagnostic evaluation, which is a common and critical mechanical component for many industrial machinery systems, including those used in the power plant, transportation, and manufacturing sectors.

Fiorucci, T., and McBride, J. 1994. Phase-Synchronized Enhancement Method for Machinery Diagnostics. *Research and Technology 1994*.

Jong, J.; Jones, J.; McBride, J.; and Coffin, T. December 1991. Correlation Identification Between Spectral Components in Turbomachinery Measurements by

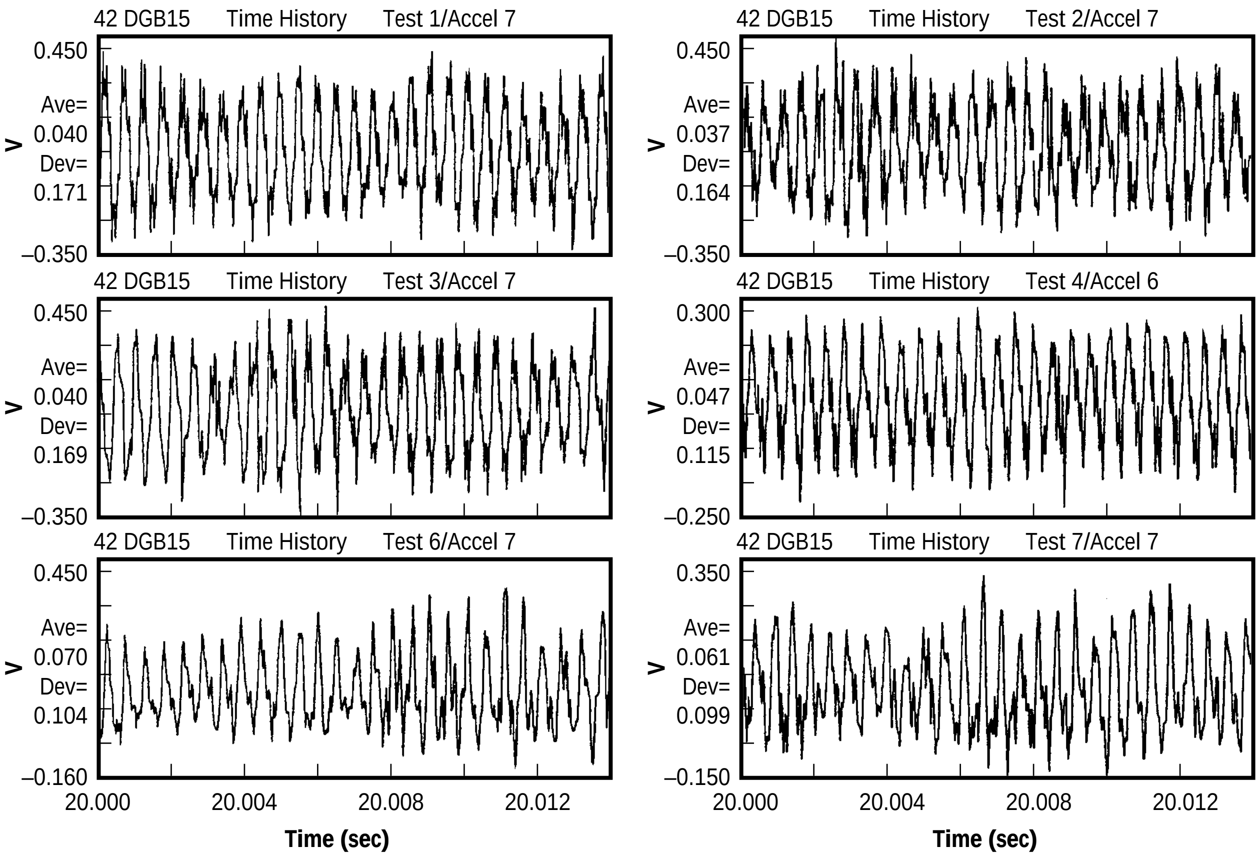


FIGURE 79.—Raw signal of gearbox test data with 500 average (fundamental frequency = Sync).


Generalized Hyper-Coherence. Third International Machinery Monitoring and Diagnostic Conference.

Jong, J.; Jones, J.; McBride, J.; Fiorucci, T.; and Zoladz, T. 1994. Phase-Synchronized Enhancement Method for Space Shuttle Main Engine Diagnostics. NASA Conference on Advanced Earth-to-Orbit Propulsion Technology.


**Sponsor:** Space Shuttle Main Engine Office

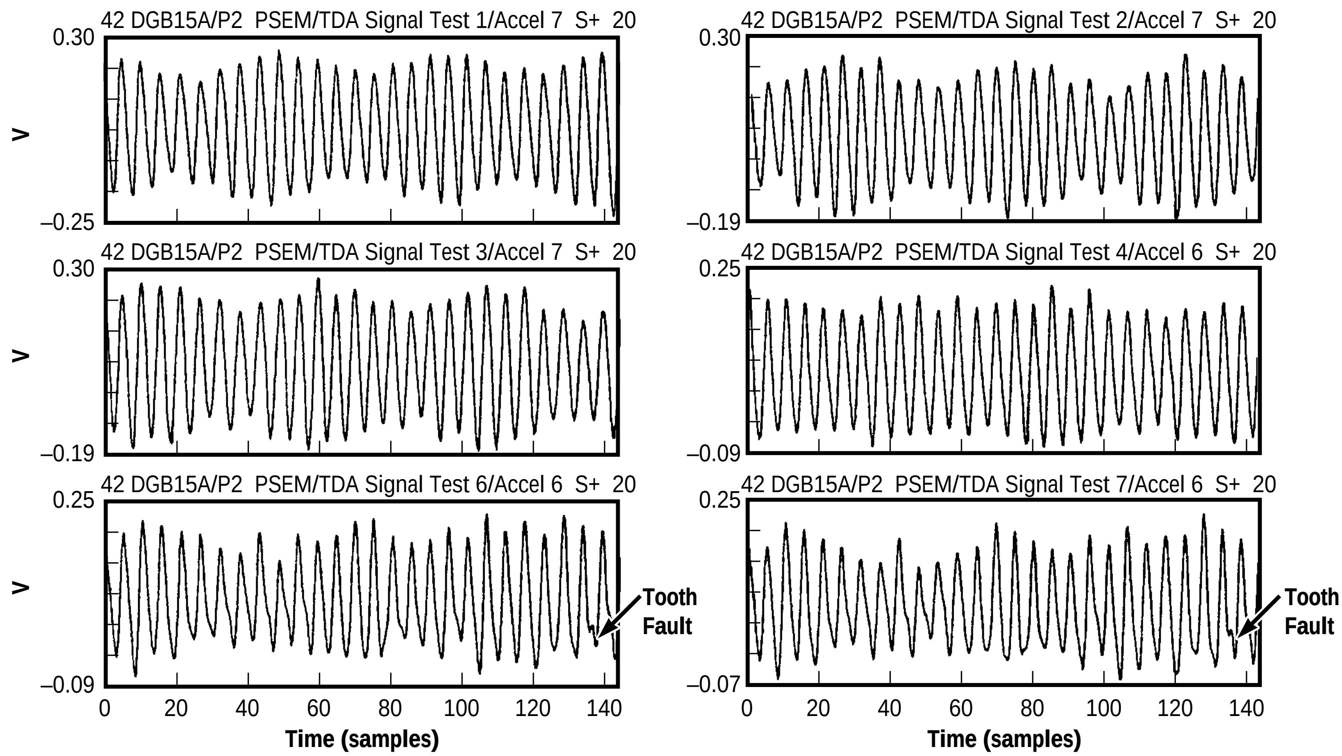


FIGURE 80.—Synchronous phase-averaged signal of gearbox test data with 500 averages (fundamental frequency = Sync).